Coastal Mixing

Eric A. D'Asaro
APL/UW 1013 NE 40th Str, Seattle, WA 98105
phone: (206) 685-2982 fax: (206) 543-6785 email: dasaro@apl.washington.edu

Ren Chieh Lien
APL/UW 1013 NE 40th Str, Seattle, WA 98105
phone: (206) 685-1079 fax: (206) 543-6785 email: lien@apl.washington.edu

Award Number: N00014-94-1-0024
http://poseidon.apl.washington.edu/~dasaro/HOME/

LONG-TERM GOALS

I seek to understand the mechanisms of turbulence and mixing in shallow water sufficiently well to be able to specify useful parameterizations for coastal circulation models. I seek to understand the links between mixing rates, the circulation and productivity of the coastal ocean.

OBJECTIVES

The short-term objective is to make mixing and circulation measurements in the Oregon upwelling system and test the theoretical turbulence parameterizations developed by D'Asaro and Lien (2000) using this data.

APPROACH

Neutrally buoyant Lagrangian floats were deployed on the Oregon Shelf during the summers of 2000 and 2001. The float motion measure water parcel trajectories. High frequency measurements along the float trajectories measure the mixing dynamics. Our primary task in FY02 was to analyze these data.

The Lagrangian floats (see picture) are the latest version of Lagrangian float technology that we have been developing since about 1990. They are designed to accurately follow the three-dimensional motion of water parcels, particularly at the time scales of mixing. The float's buoyancy is adjusted to maintain it at the same density as the surrounding seawater. A large folding drogue increases the vertical drag. Sensors on the float measure the changes in water properties following the water. These measurements are used both scientifically and to maintain the Lagrangian behavior of the float. Measurements are made autonomously for up to several months. Operational data is relayed to shore and mission parameters controlled via two-way satellite telemetry. These transmissions are made during periodic surfacings of the float, which also provide profiles of upper ocean properties and GPS fixes. Scientific data, typically several hundred Mbytes, is stored internally and extracted after the float is recovered.

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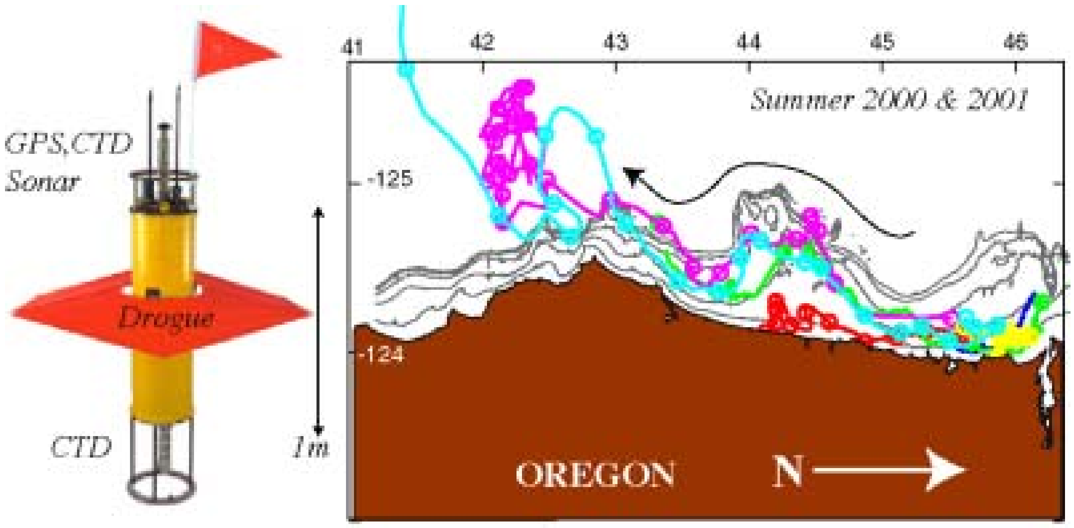

Figure 1. Left: Lagrangian float consisting of an approximately 1m long pressure hull with CTD and sonar sensors mounted on the endcaps, a folding cloth drogue in the middle and recovery equipment on the top. Right: Lagrangian floats deployed off Oregon in 2000 and 2001 traveled south along the coast; some were ejected offshore, others upwelled to the coast.

These floats are designed to easily accommodate a variety of sensors. All measure pressure and carry at least one CTD, since these instruments are necessary to operate and ballast the float. Two auxiliary instrument suites were deployed in 2001. A ``mixing" float carried two CTD's, one on each end of the float, a high accuracy Doppler sonar which measured vector velocity near the top CTD and other experimental sensors. This enabled shear, strain and Richardson number to be measured. A ``Biofloat" (funded internally by APL/UW) carried chlorophyll fluorescence and irradiance sensors.

WORK COMPLETED

In the summers 2000 and 2001, a total of 6 floats deployments were made. Two ``mixing floats" and one "biofloat" were deployed in late July, 2001 on the northern Oregon coast (see Fig. 1) using a fishing boat. All were recovered; two traveled south past Cape Blanco, were ejected westward in the offshore jet and were recovered in mid-October on the R.V Wecoma. The floats proved highly reliable; all of our problems were caused by operator error rather then hardware problems. All of the sensors worked well. In particular, the onboard ambient noise measurements were found (by J. Nystuen APL/UW) to correlate very well with local wind speeds.

RESULTS

Horizontal circulation of the Oregon Shelf The horizontal motion of the floats (Fig. 1) confirmed what has been observed previously: The crosshelf circulation is due both to the upwelling circulation, illustrated in the float data most dramatically by the motion of one float from middepth midshelf to the beach, and to energetic cross-shelf jets, clearly shown by the transport of several floats offshore near Cape Blanco.

Vertical circulation on the Oregon Shelf The floats make accurate measurements of vertical velocity, a quantity that is not routinely measured. The data show that water parcels travel across the upper 20-40m of the water column with a period of roughly a month. This motion is primarily associated with eddies, not obviously with the upwelling circulation. These vertical motions act to bring nutrient rich water to the euphotic zone. A simple model of productivity controlled by this vertical motion predicts a vertical nitrate flux of 3×10^{-4} μM ms^{-1} roughly enough to support a net productivity of 28 mM C m^2 day^{-1}.

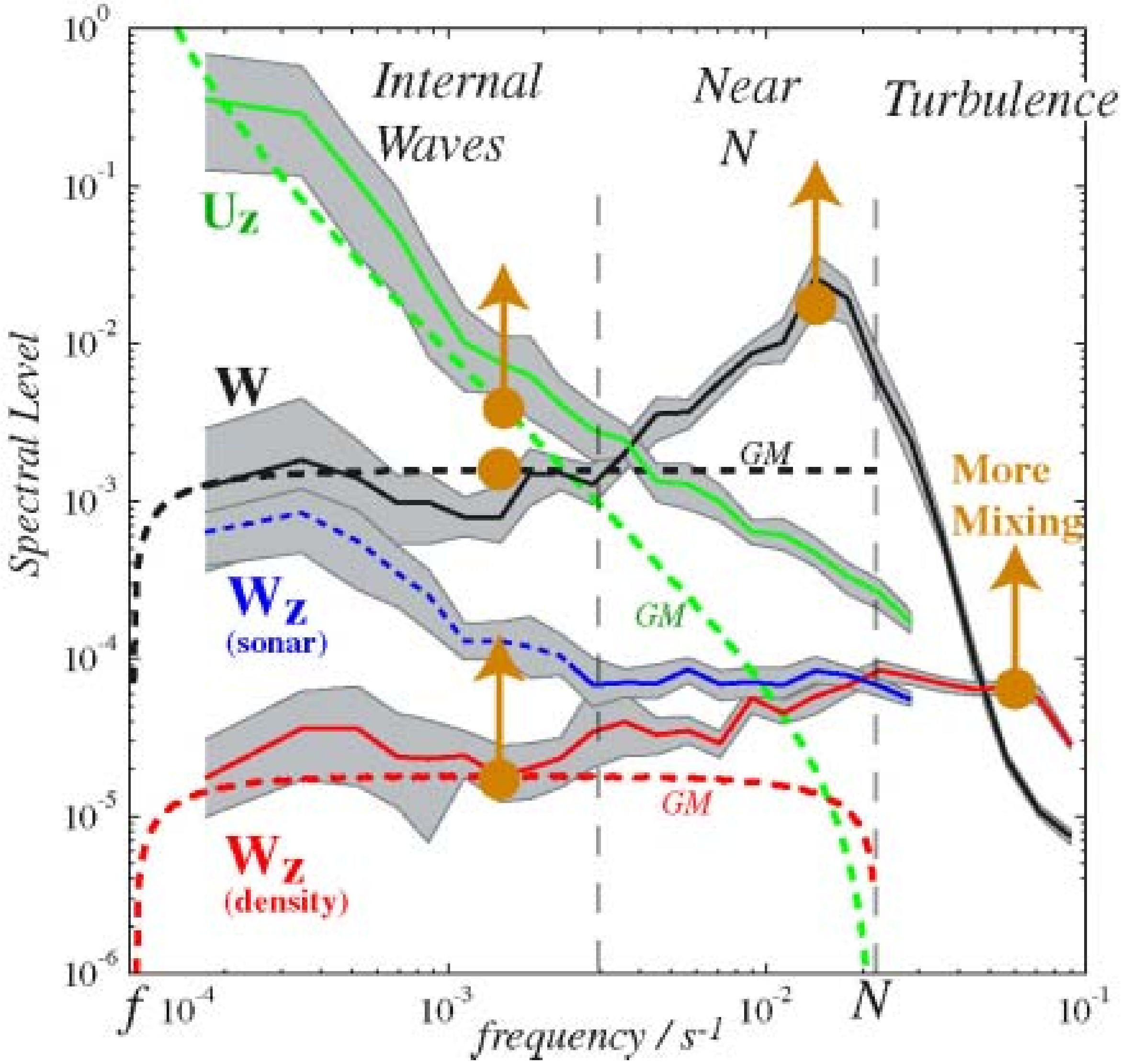

Figure 2. Sample Lagrangian frequency spectra from float on Oregon shelf. The float measures a variety of spectra including vertical velocity from pressure (W, black), vertical derivative of vertical velocity over 0.7m from sonar (Wz, blue); vertical derivative of vertical velocity over 1.4m from density (Wz, red); vertical derivative of horizontal velocity over 0.7m from sonar (Uz, blue). Dashed lines for each quantity indicate the spectrum predicted by the Garrett-Munk model. Orange arrows indicate variation of spectrum during periods of strong mixing.

Internal Wave/Mixing Dynamics A major long-term focus of this work is to use the unique ability of the floats to measure Lagrangian quantities to both understand the physics of small-scale mixing and to use this understanding to make long-term autonomous measurement of ocean mixing rates. The mixing floats measure a variety of quantities on the meter-scale as shown in Fig. 2. This scale is at the boundary of the internal wave dynamics, at larger scale, and turbulence at smaller scale. Its dynamics is therefore not very well understood.

Observed spectra divide into three frequency regions, labelled in Fig. 2. Below about N/10, spectra of W, Wz and Uz are close to their Garrett-Munk values. In regions of higher energy, indicated by the orange arrows, the Uz and Wz spectra rise together. These are all characteristics of internal waves. Thus ***low frequencies are dominated by internal waves***. However, the W spectrum varies less than the Wz and Uz spectra. Thus ***small scale internal waves are more variable than the large scale waves***.

At frequencies between 0.1 N and N the situation is more confusing and the subject of ongoing research. Our tentative conclusions are: ***Vertical velocity is dominated by low mode internal waves.*** This follows from the large peak in W, but not in Wz. ***Meter-scales show strong internal wave influence, but are more complex***. The larger increase of Uz above the Garrett-Munk level compared to Wz violates simple internal wave dynamics as does the larger value of the sonar-measured Wz compared to the density measured Wz. The gradual increase of Wz from the low frequency internal wave levels to the turbulence levels above N indicates a change from internal wave to turbulence dynamics.

At frequencies above N the spectral levels indicate the mixing rate. Following Lien et. al. (2002) the level of the white spectrum of Wz at frequencies above N is assumed proportional to χ, the rate of dissipation of density variance. Assuming this and using the Osborn Cox method, the diapycnal diffusivity K can be computed. A second estimate of K is obtained from the shear measurements and N using the parameterization of Kunze et. al. (1990). The two estimates agree within the usual large variability of mixing measurements.

Mixing Rates on the Oregon Coast Using the two methods described above, diffusivity in the themocline averaged over several days is found to vary from about 10^{-5} to 10^{-4} m s^{-2} . The larger values are associated with increased shear, mostly driven by wind events.

IMPACT/APPLICATIONS

Technically, the program has demonstrated the ability to operate Lagrangian floats for many months, controlled by two-way satellite communication and carrying a variety of multi-disciplinary sensors. With the higher bandwidth of *Iridium* satellites now available, such floats will be able to measure a wide range of environmental parameters and transmit them to shore in nearly real time. In particular, the ability to measure mixing rates remotely and autonomously for long periods will provide an ability to survey the geography of mixing.

TRANSITIONS

None

RELATED PROJECTS

These floats are nearly identical to those currently being used in the CBLAST study of air-sea interaction in hurricanes. These measurements acted as a proving ground for some of the CBLAST sensors.

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